MODULE 8:

Coupling Source Terms to Probabilistic Event Analysis (CET end-state binning)

The Problem

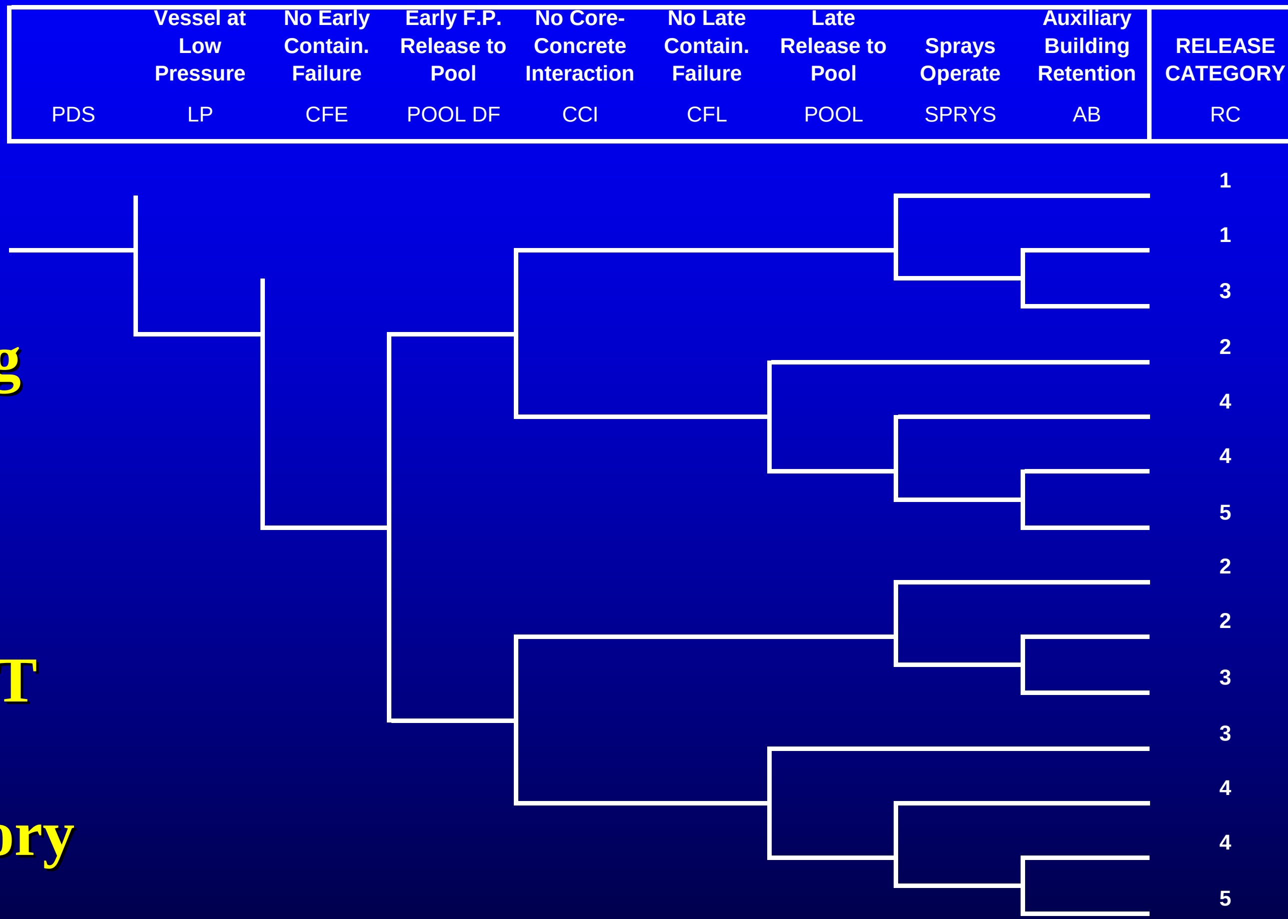
- A probabilistic treatment of severe accident progression leads to numerous possible pathways that an accident might proceed in time
  - For a given PDS, the CET expands into many branches, each representing a distinct accident progression
- It is simply impractical to 'calculate' a source term for each pathway through the CET.

➔ How can you characterize the source term for each pathway through the CET with a limited number of detailed calculations?

Solution: CET End-state Binning

- Rather than ‘calculate’ a source term for each end-state of the CET, define ‘rules’ to group end-states with similar source terms.
  - Each group is referred to as a source term ‘bin’ or ‘release category’
  - Rules (binning criteria) are based on knowledge gained from multiple source term calculations

Example Release Category Assignments



Process similar to PDS analysis

- Define binning criteria from results of calculations
- Link each CET end state to a unique Category

The Process of Developing Rules for Source Term Binning

1) Perform preliminary calculations of fission product release as part of accident progression analysis
   - Start with dominant accident sequences from Level 1
   - Also examine low-frequency, but potentially high source term sequences

2) Review results to identify features of plant design and accident phenomena that control magnitude/timing of release

Example: Preliminary Calculations

Station Blackout

System or Phenomenon State	Low Pressure Cases				
	2	4	5	6	8
DC power for 6 hrs	Yes	Yes	Yes	Yes	Yes
RCS Depressurization	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Functional Containment Vent	No	No	No	Yes	Yes
Functioning Containment Spray	No	Yes	Yes	No	Yes
Ex-vessel debris quench	No	Yes	No	No	No

System or Phenomenon State	High Pressure Cases				
	1	3	7	9	10
DC power for 6 hrs	Yes	Yes	No	Yes	No
RCS Depressurization	**No**	**No**	**No**	**No**	**No**
Functional Containment Vent	No	No	Yes	Yes	Yes
Functioning Containment Spray	No	Yes	No	Yes	Yes
Ex-vessel debris quench	No	Yes	No	Yes	Yes

- **Develop an initial list of calculations based on results of PDS analysis**
  - **At least one calculation for each class of accident sequences**
  - **Consider variations in variables known to influence severe accident progression and source term**

Release Fraction as a Measure for Comparing Source Terms

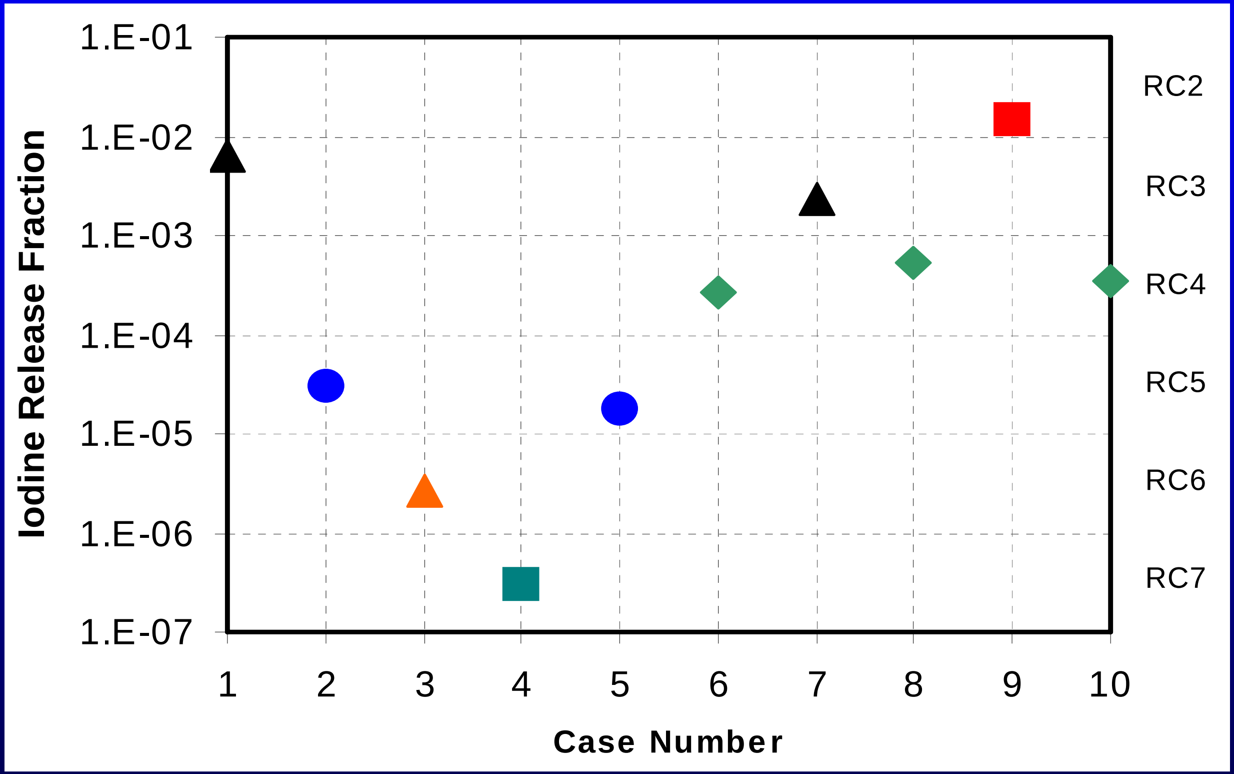
- "Bin" or group calculated source terms into broad classes based on magnitude and timing of release to the environment
  - Release fractions for Iodine (I-131) and Cesium (Cs-137) are established measures of early and long-term health effects, respectively
  - Binning criteria can be based on one, or both measures

Fractional Release of Initial Core Inventory

Release Category	Lower Bound	Upper Bound
RC1	1.0	0.1
RC2	0.1	0.01
RC3	1.E-2	1.E-3
RC4	1.E-3	1.E-4
RC5	1.E-4	1.E-5
RC6	1.E-5	1.E-6
RC7	1.E-6	1.E-7
RC8	No release	

Example: Results of Preliminary Calculations

Case	Iodine Release Fraction
1	6.4E-03
2	3.0E-05
3	2.7E-06
4	3.0E-07
5	1.8E-05
6	2.6E-04
7	2.3E-03
8	5.3E-04
9	1.5E-02
10	3.5E-04



Example: Observations from Preliminary Calculations

- Factors in the calculated accident progression that explain differences in source terms
  - Containment failure mode
    - Early vs late; rupture vs leak; vent
  - Reactor vessel pressure at time of lower head failure
- Additional factors that might be important, but insufficient information to be certain
  - Coolability of debris after lower head failure
  - Depth of water covering ex-vessel core debris
  - Leak rate (hole size) in containment pressure boundary

Source Term Analysis Process (continued)

3) **Perform additional calculations, as needed, to**
   - **Determine source term for non-dominant accident sequences**
   - **Confirm design features & accident phenomena that govern release**
4) **Define source term binning parameters**
   - **Governing design features/accident phenomena**
5) **Identify a unique calculation that represents the source term for each release category**
   - **Perform additional calculations, if needed, for some release categories**

Example: Additional Calculations

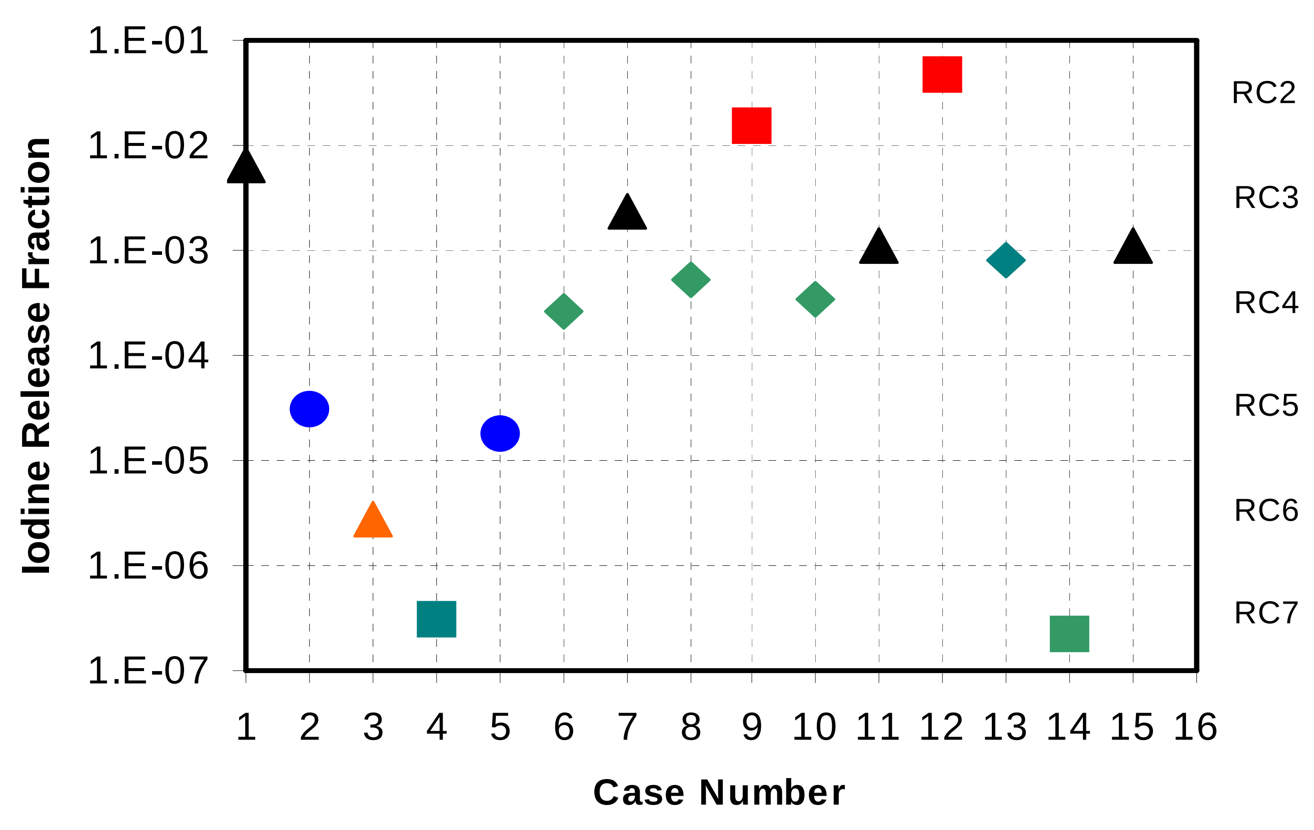
System or Phenomenon State	Low Pressure Cases						
	2	**4**	**5**	**6**	**8**	**11**	**13**
DC power for 6 hrs	Yes	Yes	Yes	Yes	Yes	Yes	Yes
RCS Depressurization	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Functional Containment Vent	No	No	No	Yes	Yes	No	Yes
Ex-vessel debris quench	No	Yes	No	No	No	No	Yes
Increased Containment Leakage	No	No	No	No	No	Yes	No

System or Phenomenon State	High Pressure Cases						
	1	**3**	**7**	**9**	**10**	**12**	**15**
DC power for 6 hrs	Yes	Yes	No	Yes	No	No	Yes
RCS Depressurization	**No**	**No**	**No**	**No**	**No**	**No**	**No**
Functional Containment Vent	No	No	Yes	Yes	Yes	No	Yes
Functioning Containment Spray	No	Yes	No	Yes	Yes	No	No
Ex-vessel debris quench	No	Yes	No	Yes	Yes	Yes	Yes

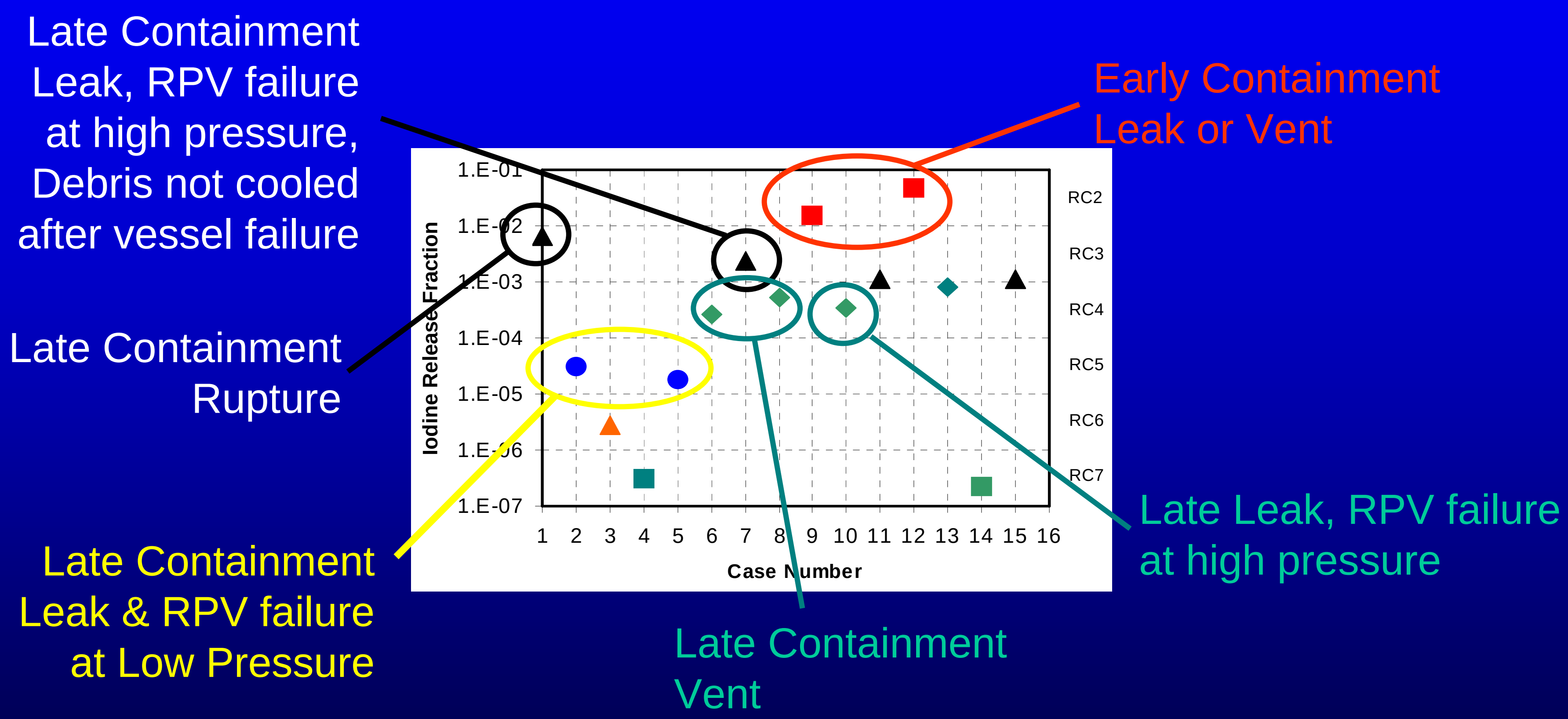
- Clarify the effects of specific phenomena
  - Increased leakage
  - Deep pools of water for scrubbing ex-vessel releases

Example: Complete Set of Calculations

Case	Iodine Release Fraction
1	6.4E-03
2	3.0E-05
3	2.7E-06
4	3.0E-07
5	1.8E-05
6	2.6E-04
7	2.3E-03
8	5.3E-04
9	1.5E-02
10	3.5E-04
11	1.1E-03
12	4.8E-02
13	8.1E-04
14	2.2E-07
15	1.1E-03
16	1.5E-03



Search for Common Characteristics of Accident Progression that Explain Differences in Release



Result: Common Features form Basis for Source Term Binning Criteria

Release Category	Containment Performance Early	Containment Performance Late	RV Pressure @ VB	Debris Cooling
RC-1	Rupture	-	-	-
RC-2	Leak	-	-	-
	Vent	-	-	-
	Isolation Failure	-	-	-
RC-3	-	Rupture	-	-
	-	Leak	High	No
RC-4	-	Vent	-	-
	-	Leak	High	Yes
RC-5	-	Leak	Low	No
RC-6	-	Leak	High	No
RC-7	-	Leak	Low	Yes

Typical Source Term Binning Characteristics

- Time, size & location of containment failure
- Plant or accident features that attenuate airborne fission product concentration
  - Release path through auxiliary building(s)
  - Atmosphere sprays
- Effectiveness of ex-vessel debris cooling
- Availability of water after RPV lower head failure
  - Cover debris with pool of water (scrubbing)
  - Cool RPV surfaces reduces revolatilization

Cautions:

Potential Traps in Source Term Binning Criteria

- **Characteristics important to the release & transport of some species may not be important for others; examples:**
  - **Noble gases transport always a special case.**
  - **Iodine is transported primarily in soluable form; i.e, strongly affected water (pools/spray); other species not as sensitive to presence of water**
  - **CsOH and Te can be chemically bound to stainless steel structures when other volatile species can be re-volatilized**

Using Iodine/Cesium for source term binning is a surrogate for direct calculation of health effects; trends should not be broadly applied to other species.

Cautions (2):

Potential Traps in Source Term Binning Criteria

- Different definitions of "early" and "late" are used in different studies
  - "Early" containment failure in some Level 2 PSAs means "at or before time of RPV failure"
  - "Early" in other PSAs, may represent a specific time (e.g., x.x hrs) based on (Level 3) PSA assumptions regarding offsite consequences

Either definition can be used, depending on objectives of the study.
Terms should be carefully defined in PSA documentation.

Summary

- Integrated severe accident progression and radionuclide release/transport calculations provide the primary basis for supporting CET quantification and source term assessment
  - Sensitivity calculations are necessary to support confidence in results obtained from baseline calculations
  - Calculations should address wide range of accident sequences
- Results of detailed calculations used to identify characteristics of severe accident behavior that govern source term
  - Characteristics used to develop “rules” or “binning criteria”
  - Apply binning criteria to end-states of CET to assign each path to a release category